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**Innovation and Knowledge Links in Metropolitan
Regions - The Case of Vienna**

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1 Introduction

Metropolitan regions are usually regarded as locations with excellent preconditions for innovation and knowledge based sectors, since they tend to be the key centers of research, education, financial and business services and culture. They often have a highly qualified work force as well as good living conditions which attract further talent and skills. They also provide access to relevant resources, inputs and customers. Given the high density and large variety of knowledge generating organisations present in metropolitan regions and the good availability of expertise and skills, these areas are acknowledged to be important nodes in the knowledge-based economy (see, for instance, Brandt et al. 2009). It is still a matter of debate and of measurement whether Marshallian externalities (i.e. advantages of specialization and of industrial clustering), Jacobian externalities (advantages of diversification and of urbanization) or advantages of related variety (see, for instance, Frenken et al. 2007) prevail in such locations and are the most favorable ones for innovation. But there is some agreement that “institutional thickness”, i.e. a high density of economic activities, knowledge organizations and supporting institutions, and cognitive, spatial and other types of proximities are supporting and enhancing innovation (Brower et al. 1999, Simmie 2003, Boschma 2005).

However, there is also empirical evidence showing that this positive relation between metropolitan regions and innovation may not be as clear as it seems to be at the first glance. In fact, many metropolitan regions suffer from various kinds of innovation problems and impediments to knowledge exchange which might produce other results than those stated above, such as the following:

- Some regions might lack particular elements of a regional innovation system (RIS), such as leading research organizations in certain fields, international companies or knowledge intensive firms, innovation intermediaries and knowledge transfer organizations, innovation finance and venture capital (problem of “missing elements”).
- Then, the two RIS subsystems of knowledge generation and of knowledge application might be weakly connected and there might be a lack of networking between firms in the RIS and in relevant clusters (Autio 1998, Cooke et al. 2000). Elsewhere we have referred to such a constellation as “fragmented” innovation system (Tödtling and Trippel 2005).
- For historic and other reasons there might be also a specialization in low tech or non-innovative industries or a lack of innovative functions such as R&D and marketing (structural problem).
- Finally, the behavioral attitudes and routines of managers and of the labor force might hamper innovation, i.e. there might be a lack of innovation culture in a particular region (Saxenian 1994, Tödtling and Trippel 2008).

The case of the metropolitan region of Vienna is interesting in this context since it can be regarded as “institutionally thick” as regards the general knowledge infrastructure and – organizations. Within Austria, the Vienna region is the prime centre of universities, schools and research organizations in many fields. It is also a central location for knowledge intensive services as well as for regional headquarters of multinational companies (for Austria and its neighboring Eastern European countries), and it is well connected via a good transport and telecommunication infrastructure. Still, at least until the mid 1990s, Vienna has faced a few innovation problems:

- It has suffered to some extent from the weaknesses of Austria’s national innovation system (NIS) expressed in its backward situation as regards indicators of the knowledge economy (low R&D quota, weak patenting activities, poor availability of venture capital: see Cooke et al. 2007). Although Vienna has performed better in many of these indicators than the rest of Austria it was not able to fully overcome some of those weaknesses.
- Vienna seemed to have developed only few networks and knowledge interactions in the field of innovation in the past (Tödtling 2002, Fritsch 2003), thus reflecting

features of a “fragmented metropolitan RIS” (Tödting and Tripl 2005). Such a problem of fragmentation would be a particular problem for the development of knowledge intensive sectors in a region, since these sectors strongly depend on intensive interactions between research and industry, as well as on vivid knowledge exchange among companies (Saxenian 1994, Keeble et al. 2000).

In the following, we examine whether or not the key deficiency of Vienna’s RIS in the past, i.e. fragmentation, is also a characteristic feature of new knowledge intensive sectors, which have emerged and grown in the last few years in the region under investigation. In the empirical part (section 3) we focus on two key industries in this respect, that is medical biotechnology and ICT, and investigate the nature of knowledge and innovation links of Viennese firms in those sectors. As we have argued in another paper (Tödting et al. 2006) it is useful to differentiate between different types of knowledge linkages in this context, including market relations (e.g. R&D contracts and licensing), formal co-operations (e.g. R&D partnerships), knowledge spillovers (e.g. monitoring of competitors) and informal networks. In addition, we look at the spatial levels (regional, national, international), as well as the key partners involved in those relationships.

2 Metropolitan Regions and Innovation – The View from the Literature

In the past years a number of studies have investigated the geography of innovation and the role of metropolitan regions in the innovation process (Tödting 1992, 1994, Feldman 1994, Audretsch 1998, Baptista and Swann 1998, Fritsch 2000, 2003, Fischer and Fröhlich 2001, Gehrke and Legler 2001, European Commission 2003). The following patterns were identified:

- R&D activities, patenting and major product innovations are usually highly concentrated in larger agglomerations (Brower et al. 1999, Feldman and Audretsch 1999, Breschi 2000, Paci and Usai 2000, Fischer et al. 2001, Gehrke and Legler 2001, Simmie 2003).
- Knowledge spillovers can be observed in industrial clusters and agglomerations and they are spatially bounded to a certain geographical distance from these centers (Jaffe et al. 1993, Audretsch and Feldman 1996, Anselin et al. 1997, Baptista and Swann 1998, Baptista 2003, Bottazzi and Peri 2003).

- There is still a debate in the literature whether specialized (Marshall/Arrow/Romer) or diversified (Jacobs) agglomerations are more conducive for innovation. While some authors (Baptista and Swann 1998, Porter, 1998, Cooke 2002, Fritsch and Franke 2004) argue in accordance with Marshall for innovation advantages of specialization, others state in accordance with Jacobs that diversification is more favorable (Tichy 2001). Feldman and Audretsch (1999) argue more specifically that innovation is stimulated by the presence of complementary industries sharing a common knowledge base. Similarly, taking an evolutionary perspective, Frenken et al. (2007) have pointed out that “related variety” might be the most supportive industrial environment for innovation in the long run since it allows to combine synergetic advantages of specialization (within broader sectors) with the advantages of diversity and variety (among subsectors).

Peripheral regions are regarded as less innovative in comparison to agglomerations:

Companies there have often a lower R&D intensity and fewer product innovations, and innovation is more focused on product modifications and new processes instead (Tödtling, 1992, Feldman 1994, Fritsch 2000). Also old industrial areas were found to be less innovative with a focus on incremental and process innovation due to predominance of mature industries and externally controlled firms (Tödtling 1992, Cooke 1995, Tichy 2001). In general, thus, there is some indication of metropolitan regions being more innovative than other regions. The situation is more complex, however, as we also may find innovative clusters in rural areas (Fritsch 2003), innovative restructuring in old industrial areas (Tripl and Otto 2009), as well as innovation problems in metropolitan regions.

A number of studies have investigated regional innovation in the framework of innovation systems (De la Mothe and Paquet 1998, Tödtling and Kaufmann 1999, Cooke et al. 2000, Sternberg 2000, Asheim et al. 2003). These RIS based studies have related the innovation performance of firms to the character of their networks and to institutional factors (Thomi and Werner 2001, Doloreux 2002, Fornahl and Brenner 2003, Cooke et al. 2004). Departing from the main deficiencies of RIS, Tödtling and Tripl (2005) have drawn a distinction between “organizationally thin RIS”, “RIS characterized by lock in” and “fragmented RIS”. In particular the problem of fragmentation can often be assigned to metropolitan regions.

Summing up the view from the literature, we find that metropolitan regions are generally regarded as centers of innovation, benefiting from knowledge externalities and agglomeration economies. Leading research organizations and universities, business services, as well as headquarters of international firms and high-tech companies are often concentrated in metropolitan regions (Moulaert and Tödting 1995, Keeble and Wilkinson 1999). As a consequence, R&D activities, patenting activities and major product innovations are usually above the country average (Brower et al. 1999, Feldman and Audretsch 1999, Fischer et al. 2001, Gehrke and Legler 2001, Simmie 2003). Given the good availability of crucial innovation inputs and the high density of knowledge generating and exploiting organizations, metropolitan regions are regarded as important nodes in the emerging knowledge-based economy (Brandt et al. 2009). However, not all metropolitan regions are such centers of innovation. Some are lacking dynamic clusters of innovative firms, despite the fact that individual technology companies, R&D activities and research organizations may be present. There may exist highly developed public research and educational institutions and a dense supply of knowledge intensive business services. However, the problem of fragmentation, i.e. the lack of networks and of interactive learning seems to represent an important innovation barrier in some metropolitan regions. The two RIS subsystems of knowledge generation and application then operate separately, as university-firm links are at a low level. Also, innovation networking among local companies may be weak (Fritsch 2003), even if customer and supplier links among firms exist. As a consequence, the development of new technologies and the formation of new firms are often below expectations. Examples here could be the region of South East Brabant in Holland (Eindhoven: Cooke et al. 2000) and also the metropolitan region of Frankfurt shows some of the stated features. Schamp (2001) in an interesting case study for Frankfurt observed a weak regional networking and a continuing erosion of innovative functions in particular for the more established and internationalized industries chemicals and automobiles. Better developed innovation networks were identified for the new sectors biotechnology and financial services, however. Also for Vienna some previous studies have identified some innovation problems, in particular of fragmentation. There was a considerable gap in the interaction between a relatively well developed subsystem of knowledge generation (universities and research organizations) and the subsystem of knowledge application and commercialization (Tödting 2002, Fritsch 2003). In the following we are going to investigate to which extent this also applies for two selected knowledge intensive sectors, ICT and biotechnology which we have studied in greater detail. In particular for these kinds of sectors, both local and international knowledge interactions

and networks are regarded to be of key importance for the innovation performance and competitiveness (Camagni 1991, Saxenian 1994, Keeble and Wilkinson 1999, Bathelt et al. 2004, Cooke et al. 2007).

3 Innovation and Knowledge Links in the Vienna Metropolitan Region

This section deals with the case of the metropolitan region of Vienna. After a brief overview on basic socio-economic features we are going to explore in more detail the knowledge generating capacity and innovation potential of the region. This is followed by an analysis of spatial pattern of innovation partnering and knowledge sourcing activities of firms in two key knowledge-based sectors: medical biotechnology and information and communication technologies (ICT). The key aim of this section is to explore whether these two sectors reflect a traditional key weakness of Vienna's RIS, that is, fragmentation. Indeed, in the past, several studies have shown that there is little innovation networking between companies and research organizations (Fröhlich and Gassler 1999, Rohn 2000), pointing to a serious system failure of the RIS Vienna. According to Rohn (2000) this RIS deficiency was partly the outcome of a certain mismatch of the research done at local universities and the needs of the firms present in the region.

Methodological notes

We use data from the Austrian national statistic office and from Eurostat to explore the socio-economic characteristics and innovation capacity of the Vienna metropolitan region. The empirical analysis of knowledge networking in the ICT and biotech sector draws on data collected in the context of two research projects. The findings reported below for biotechnology stem from the project "Collective Learning in Knowledge Economies: Milieu or Market?" (2002-2004) which received financial support from the Austrian Science Fund. This analysis has been updated in a follow-up project on the Vienna Biotechnology Cluster in 2005-2006. The results are based on face-to-face interviews carried out for both projects. We conducted 41 interviews, using semi-standardized questionnaires. A number of 21 interviews have been taken with companies. This sample covers big pharma firms, young biotechnology companies and suppliers. Moreover, we have interviewed 11 representatives of knowledge providers (including university institutes and other public and private research organizations). Finally, nine interviews have been taken with representatives of the policy and supporting

system, four of which have been with regional actors and five with national ones. The empirical results for the ICT sector draw on data gathered in the research project “Innovation and knowledge networks in the Vienna ICT cluster” (2006-2007), which has been financially supported by the Jubilee Fund of the city of Vienna for the Vienna University of Economics and Business. In this project, a web-based survey has been carried out. We sampled 1084 Viennese ICT firms which were listed in the AURELIA database and invited them to fill in a questionnaire. A number of 73 firms responded, yielding a rate of return of about 7%. There are, thus, differences in the methodological approach (face-to-face interviews for studying biotechnology, web-based survey for analyzing the ICT sector). These differences in methodology, however, do not constitute major limitations or drawbacks for our analysis, because our aim is not to directly compare biotechnology and ICT, but rather to find out, whether or not these two sectors suffer from fragmentation.

Socio-economic features and innovation potentials of the Vienna metropolitan region

Vienna is the federal capital of Austria and it constitutes one of the country’s nine provinces. As shown in Table 1, it covers an area of 415 square kilometers (0.5% of Austria), hosting more than 1.6 million inhabitants in 2008 (20% of the Austrian total). Vienna is by far the richest Austrian region. Its regional gross domestic product per head is clearly above the Austrian average. However, in the last 10 years annual GDP growth has been slightly below the national average. In 2006 Vienna had an unemployment rate of 8.8%, whilst the Austrian average amounts to only 4.7%. In 2001 Vienna hosted about 88,000 plants (representing 22% of the Austrian total), employing 821.458 persons (24% of the Austrian total). Using the most recent data (which are, however, not available at the plant level but only at the firm level), we find almost 70,000 firms which provide jobs for more than 600,000 workers in 2006.

Table 1: Socio-economic characteristics of the Vienna metropolitan region

	Vienna	Austria
Area, km2 ^[1]	414.87	83,871.97
Population (2008) ^[1]	1,677,867	8,331,930
Number of plants (2001) ^[1]	87.691	396.238
Number of employees (2001) ^[1]	821,458	3,420,788
Number of firms (2006) ^[2]	68,322	290,735
Number of employees (2006) ^[2]	614,938	2,308,789
Unemployment rate (2006) ^[1]	8.8 %	4.7 %
Gross domestic product per head (2005) ^[1]	41.100	29.800
	(138)	(100)
Annual GDP growth (period: 1996-2005) ^[1]	3.2	3.5

Sources: [1] Statistik Austria (2009); [2] Statistik Austria (2008); own calculations

The metropolitan region of Vienna represents Austria's undisputed centre of knowledge production and innovation. Vienna is well endowed with knowledge generating organizations. It hosts not fewer than 25 public universities and art academies. Furthermore, there is a large number of non-university research organizations, technical colleges and innovation centers. The most important knowledge production organizations relevant for business innovation are the University of Vienna, the Technical University of Vienna, the Medical University of Vienna and the Vienna University of Natural Resources and Applied Life Sciences. Moreover, there are 50 research institutions of the Austrian Academy of Sciences, more than 100 institutes and research sites of the Ludwig Boltzmann Society (focus on human medicine), about 250 further non-university research institutions in different fields and several technical colleges.

In the Vienna metropolitan region we find more than 136,000 students or a share of 54% of the Austrian total and about 19,000 R&D workers, representing 39% of the Austrian total. Whilst the share of R&D workers in total employment amounts to 4.58% in Vienna, the respective percentage for Austria as a whole is only 2.14%. Although the majority of R&D personnel can be found in the business sector (56%), this share is lower in Vienna than it is in Austria as a whole (69%, Table2). This implies that in Vienna the share of R&D personnel employed in the higher education sector is clearly above the national average. The distribution of R&D workers across sub-sectors points to strengths in the RIS subsystem of knowledge generation, whereas Vienna's subsystem of knowledge exploitation is somewhat weaker in comparison.

Table 2: R&D personnel (2006) and R&D expenditures in % of GDP (2006)

	All sectors	Business sector	Higher education sector	Government sector	Private non-profit sector
<i>R&D personnel (full time equivalent)</i>					
Vienna	19,207	10,784	6,671	1,620	132
(%)	(100%)	(56.1%)	(34.7%)	(8.4%)	(0.7%)
Austria	49,378	34,126	12,668	2,423	161
(%)	(100%)	(69.1%)	(25.7%)	(4.9%)	(0.3%)
<i>R&D expenditures in % of GDP</i>					
Vienna	3.54	2.09	1.15	1.15	0.02
Austria	2.46	1.73	0.59	0.59	0.01

Source: Eurostat

Table 3: Regional innovation scoreboard indicators 2006 (EU = 100)

	HRSTC	Life-Long-Learning	Med/Hi-Tech Manuf.	Hi-Tech Services	Public R&D	Business R&D	Patents
Vienna	95	139	97	159	201	154	102
Austria	67	110	97	91	97	97	118

Source: Eurostat

HRSTC: Human resources in science and technology – core (% of population)

Life-Long learning: Participation in life-long learning per 100 population aged 25-64

Med/Hi-Tech Manuf.: Employment in medium-high and high-tech manufacturing (% of total workforce)

Hi-Tech Services: Employment in high-tech services (% of workforce)

Public R&D: Public R&D expenditures (% of GDP)

Business R&D: Business R&D expenditures (% of GDP)

Patents: EPO patents per million population

From the European Regional Innovation Scoreboard (Hollanders, 2006, Table 3) we can observe that Vienna scores particularly well in public R&D (indicator of 201), as well as in business R&D (154) and in high tech services (159). A below average performance we find in the HRSTC (low share of academics) as well as in medium and high tech manufacturing. The overall patenting activity according to this data set is below the Austrian and in the EU average. Table 4 reveals, however, that Vienna has a rather good performance in high tech patents which are clearly above the Austrian average. This holds true for high-tech patents in general, and is also observable for the fields of ICT and biotech in particular.

Table 4: Patent indicators

	High-tech patents (2004) ¹	ICT patents (2004) ²	Biotech patents (2004) ³
Vienna	63.77	75.88	19.23
Austria	22.65	36.98	6.49

Source: Eurostat

¹High-tech patent applications to the EPO per million of inhabitants

²ICT patent applications to the EPO per million of inhabitants

³Biotech patent applications to the EPO per million of inhabitants

Table 5: Shares of employment (2007) – NUTS 2 level

Sector (NACE codes)	Vienna	Austria
Agriculture, hunting, forestry, fishing mining and quarrying (A to C = 01-14)	0.8	5.8
Manufacturing (D)	11.2	18.2
High and medium high tech manufacturing	5.2	6.7
Low and medium low tech manufacturing	6.0	11.5
Electricity, gas, water supply and construction (E, F)	7.9	8.6
Services (G to Q = 50 to 99)	80.1	67.1
Knowledge intensive services	41.7	30.0
Less knowledge intensive services	38.4	37.1

Source: Eurostat

Table 5 provides a comparative overview on the economic structure of Vienna and Austria. Unsurprisingly, the service sector is clearly dominating in the Vienna metropolitan region. A particular high importance of knowledge intensive services could be found here. In accordance with Table 3 above, high tech and medium high tech manufacturing, in contrast, play a minor role. This is due to the strong losses of manufacturing jobs in Vienna in the past decades (Mayerhofer 2006).

Vienna, thus, constitutes the core centre of knowledge generation and –transmission within Austria with particular strengths in public R&D and knowledge intensive services. However, so far it is unclear to which extent the business sector is able to benefit from these knowledge organizations, e.g. through dense innovation interactions. In the past there were indications that the interaction between the companies present in the region and the knowledge generating organizations was low, resulting in a rather fragmented innovation system (Tödting 2002, Fritsch 2003, Tödting and Trippl 2005). Therefore, in the following we intend to explore, whether this phenomenon of fragmentation, is also a characteristic feature of new high tech and knowledge based sectors which have emerged and grown in the last few years in the Vienna metropolitan region. Such industries are acknowledged to play a central role for the current and future competitiveness and dynamics of metropolitan regions. To observe fragmentation in these sectors would imply a serious problem for Vienna’s future competitiveness in the emerging knowledge-based economy.

Biotechnology

The metropolitan region of Vienna is by far the most important location for Austrian medical biotechnology firms. As revealed in Table 6, not fewer than 77 biotech companies (representing 67% of all Austrian medical biotech firms) could be found in Vienna, pointing to a strong geographical concentration of this emerging knowledge based sector in the metropolitan region studied here.

Table 6: Proportion of medical biotechnology companies in Austrian provinces

Region	Number of firms	Proportion of firms (%)
Vienna	77	67
Styria	10	8,7
Lower Austria	10	8,7
Tyrol	9	7,8
Upper Austria	4	3,5
Salzburg	4	3,5
Vorarlberg	1	0,8
Total	115	100

Source: BIT and LISA (2004), complemented by our own inquiry

Vienna's medical biotech industry hosts a few subsidiaries of big pharma companies such as Boehringer Ingelheim and Baxter, which perform as key actors in the local cluster. Boehringer Ingelheim's activities in Vienna comprise the company's centre for cancer research, a centre of competence in biopharmaceutical production, and its basic research subsidiary, the Institute of Molecular Pathology (IMP). Baxter Austria is the company's most important research operation outside the United States. The largest pharmaceutical producer in Austria is Novartis, a Swiss multinational company, employing more than 3,000 workers. However, in 2008, Novartis closed its research institute in Vienna to bundle these activities in its hometown Basel.

The Vienna region hosts about 25 dedicated biotech companies. Examples include Intercell (vaccines against oncological and infectious diseases), Igeneon (oncology), Austrianova (oncology, gene therapy) or Green Hills Biotechnology (oncology). About 40 % of the dedicated biotech firms were founded within the past few years and many of them employ fewer than 10 workers. Then, there are about 20 specialized suppliers operating in the area. This segment mainly consists of producers of research agents (Nano-S, Bender Med Systems), bioinformatics providers (Emergentec, Insilico) and firms performing clinical trials services. Venture capital firms and business angels are a missing element in the cluster. The

main reason for this is the bank-dominated landscape in Austria, which coincides with a preference for traditional credit instruments and a widespread aversity to risk taking. Consequently, successful companies like Intercell or Igeneon had to attract external financing from international venture capitalists and funds.

Despite the recent loss of the Novartis Research Institute (NRI), Vienna still has an excellent scientific base in medical biotechnology, comprising five universities, several hospitals and a range of other public and private research institutes. There are the Institute of Molecular Pathology (IMP) which is Boehringer Ingelheim's cancer research centre, and the Antibiotic Research institute Vienna (ABRI) which is owned by Biochemie Kundl (part of Sandoz R&D). A further strengthening of the local research base could be observed as the Austrian Academy of Sciences has established recently two new institutes, namely the Institute of Molecular Biotechnology (IMBA) and the Research Centre for Molecular Medicine (CeMM). Moreover, five co-operative research centers between university institutes and firms have been set up in the Vienna region. Finally, a technical college for biotechnology has also been created in order to improve the supply of specialized and highly skilled labor.

In the following we explore the spatial dimension of knowledge circulation that underpins innovation in the Vienna medical biotech industry. In face-to-face interviews 21 firms (see methodological notes) were asked to indicate their most important knowledge sources and to specify their location as well as the type of knowledge exchange with these sources. We identified a number of 149 knowledge linkages. As shown in Table 7, formal co-operations and R&D partnerships constitute the most important single mode of knowledge acquisition and exchange for the studied Vienna biotechnology firms. Exploring the geography of co-operative linkages we found that almost 50% of them are maintained with local partners. There is evidence for close local co-operation between academic institutions and firms (i.e. university-industry partnerships) and to a lesser extent for inter-firm collaborations. Given these results, one can hardly argue that the local biotech innovation system is suffering from fragmentation. Some of the formal linkages reflect conscious policy efforts to boost the level of interaction in the Austrian and Viennese biotech scene. In the past years, for example, several biotech related competence centers, jointly run by universities and firms, have been established in Vienna with financial support of local and national governments (for a more detailed discussion of this issue see Tödting and Trippel 2007, Trippel and Tödting 2007). To be sure, innovation networks and R&D collaborations established by Viennese biotech firms

are not confined to the local level. The studied companies have forged co-operative relations with internationally renowned knowledge centers and are also inserted into various collaborative endeavors with multinational pharmaceutical companies located elsewhere.

Furthermore, our study has shown that Vienna biotech companies make also use of knowledge and expertise which can be 'bought in the market place', pointing to the significance of respective relations such as contract research, buying of licenses, testing or knowledge related services. Overall, these linkages seem to be less important than knowledge flows via co-operation. Table 7 illustrates that market links have been mainly found at the international level. However, also local interactions of this type play a role, amounting to 30% of all market links. They include, amongst others, ties between local firms and university institutes and hospitals, being largely about contract research, the testing of assays and the buying of patents and licenses.

Apart from formal co-operation and market linkages there are also spillovers and informal links which give rise to knowledge flows in the Vienna biotechnology cluster (see Table 7). These result from regular professional meetings and talks, the reading of literature and also from the monitoring of competitors. The Vienna region is of crucial significance when it comes to analyze the spatial dimension of knowledge spillovers. The relevance of the local level, where 40 per cent of all spillovers and informal links could be observed (see Table 7), results partly from intensive informal networking between local companies and research organizations. Unsurprisingly, this phenomenon is most apparent between spin-offs and their academic parent organizations and tends to be particularly strong in those cases, where the start-up firm is located at the site of the university institute from which it emanated. Furthermore, about 25 per cent of the firms stated to have established people-based informal links with other local companies and there is also evidence of intense monitoring of competitors within the Vienna biotech industry. It is worth mentioning that the emergence of personal relationships among local actors has been supported by policy actions. Of key importance in this respect has been the organization of so called 'Life Science Circles' and other meetings which have brought local companies together, stimulating an informal exchange of ideas and experiences. Our study, however, also demonstrates that knowledge spillovers are only partially geographically bounded, as 60% could be found at the international scale (Table 7). International knowledge spillovers are the outcome of gaining new knowledge by reading scientific literature and patent specifications, by monitoring the

activities of international competitors and by establishing informal links to them and other distant firms. International congresses and fairs have been identified to play a key role in this respect.

Table 7: Types of knowledge links and their geography in the Vienna biotechnology cluster

	Total		Vienna			Austria			international		
	Number of links		With firms	With RO	<i>Total</i>	With firms	With RO	<i>Total</i>	With firms	With RO	<i>Total</i>
Market links	30	(20%)	2	8	<i>10</i>	0	0	<i>0</i>	13	7	<i>20</i>
Formal co-operations	79	(53%)	14	25	<i>39</i>	2	5	<i>7</i>	17	17	<i>33</i>
Informal links and spillovers	40	(27%)	6	10	<i>16</i>	0	0	<i>0</i>	15	9	<i>24</i>
Total	149	(100%)			<i>65</i>			<i>7</i>			<i>77</i>
RO ... research organization (universities, clinics)											

In the following we take a closer look at two specific core mechanisms of knowledge transmission, that is, spin-offs and recruitment of highly skilled labor.

Spin-off processes are a rather recent phenomenon in the Vienna biotechnology cluster. As shown in Table 8, most of spin-off companies included in our study are rather young and small. Like in other regions (Keeble and Wilkinson 2000) new firm creation in the Vienna biotech industry is a highly localized process. The overwhelming majority of all spin-out companies originated from parent organizations operating in the region. Looking at the type of incubators a clear dominance of local universities was found. These findings point to a strong localized use and transfer of academic knowledge to the industrial world, providing further evidence for the view that fragmentation is not a core problem in Vienna's emerging biotech sector.

Table 8: Characterization of spin-off companies in the sample

		number of companies	percentages
Age of firm	not older than 10 years	13	87
	older than 10 years	2	13
	<i>Total</i>	<i>15</i>	<i>100</i>
Firm size (number of employees)	1-10	8	53
	11-50	5	33
	More than 50	2	13
	<i>Total</i>	<i>15</i>	<i>100</i>
Location of parent organization	Local	14	93
	National	0	0
	International	1	7
	<i>Total</i>	<i>15</i>	<i>100</i>
Type of parent organization	Academic institution	11	73
	Firm	4	27
	<i>Total</i>	<i>15</i>	<i>100</i>

Similar results were obtained from the analysis of labor market recruitment and labor mobility of highly-skilled employees. The local level turned out to be crucially significant in this regard. For the large majority of the surveyed companies the local universities are the essential source of highly qualified labor. This was confirmed in interviews both with firms and universities. However, only little evidence for movements of skilled workers between local biotech companies was found. Importantly, we could observe an inflow of international scientific and industrial expertise. The research organizations present in Vienna attract scientists from all over the world. Even more interesting is the employment of foreign top managers in some growing Viennese biotech companies. This is noteworthy, because local managerial competencies in the field of biotechnology are a missing ingredient in the Vienna biotech cluster. Vienna biotech firms deal with this deficiency of the local system by recruiting experienced managers from abroad.

Information and Communication Technologies (ICT) Sector

The metropolitan region of Vienna is not only the key centre of Austria's emerging biotechnology sector, but it is also the core region of the nation's ICT industry. The ICT sector is older and by far larger than the biotech industry. Adopting a broad definition of the ICT sector as it has been proposed by the OECD (2004), we find more than 5,500 ICT firms in Vienna (35% of the Austrian ICT industry), providing employment opportunities for approximately 78,918 workers (61% of all Austrian ICT employees, see Table 9).

Table 9: Proportion of ICT companies in different Austrian provinces

Region	Number of firms	Proportion of firms (%)
Vienna	5575	35
Styria	1855	12
Lower Austria	2891	18
Tyrol	979	6
Upper Austria	2051	13
Salzburg	925	6
Vorarlberg	564	4
Carinthia	673	4
Burgenland	339	2
Total	15852	100

Source: Statistik Austria 2008 (own calculations)

In terms of number of firms, it is particularly the ICT subsector “NACE 72: Computers and related activities” which is dominating in Vienna. It contains almost 5,000 firms (88% of all ICT firms located in Vienna). However, due to the small size of many companies in that subsector, it “only” employs 20,250 workers (26% of all ICT workers employed in Vienna). The largest ICT subsector in terms of employees present in Vienna is “NACE 64: Post and telecommunications” (44,000 workers employed by 205 companies), followed by “NACE 72: Computers and related activities” (see above), “NACE 32: Manufacture of radio, television and communication equipment and apparatus” (12,235 workers, 79 firms), and “NACE 33: Manufacture of medical, precision and optical instruments, watches and clocks” (353 companies employing 2,324 workers). The subsector “NACE 33: Manufacture of office machinery and computers” is almost negligible both in terms of number of firms and employees in comparison.

The metropolitan region of Vienna is well endowed with knowledge generating organizations in the field of ICT. Key actors are the Technical University of Vienna (faculty of electrical engineering and information technology), University of Vienna (faculty of computer sciences), and Medical University of Vienna (Section of Medical Computer Vision, and excellence centre for telemedicine). Among the non-academic research institutes we find the Austrian Research Institute for Artificial Intelligence (OFAI) of the Austrian Society for Cybernetic Studies (OSGK) and Seibersdorf Research (medical informatics). Furthermore, there are several co-operative research institutes located in Vienna. In the field of ICT not fewer than four CD Labs and four competence centers could be found in the region.

In the following we explore the geography of knowledge links maintained by innovative Vienna ICT firms to find out whether or not this knowledge based sector suffers from

fragmentation. As already mentioned above (see methodological notes) our findings are based on a web-based survey of 73 ICT firms located in Vienna. We analyze knowledge linkages to various sources at different spatial scales and we explore the relative importance of different modes of knowledge exchange by calculating the share of Viennese ICT firms which perform such activities (and not, as done in the biotech study, by looking at the respective number of knowledge links).

Table 10: Knowledge sources and their geography in the Vienna ICT sector

	Vienna	Rest Austria	Europe	USA & Canada	Asia	Rest of the world
Customers	39,1	36,2	33,3	4,3	2,9	4,3
Suppliers	18,8	23,2	23,1	26,1	10,1	5,8
Competitors	26,1	21,7	29	10,1	1,4	1,4
Service Firms	27,5	15,9	7,2	4,3	1,4	1,4
Commercial R&D	15,9	11,6	5,8	1,4	0	2,9
Universities	31,9	15,9	10,1	4,3	1,4	0
Technical colleges	21,7	21,7	2,9	0	0	0
Non-profit R&D	5,8	7,2	4,3	0	0	0
Technology centers	15,9	8,7	2,9	0	0	0

Innovation is an important competitive strategy of the surveyed Vienna ICT companies. Not fewer than 71% of the firms reported having improved existing products in the three years prior to our study (incremental innovation). But there is also evidence for more radical forms of innovation. A share of 49 % of the sampled firms generated innovations which are new to the market (radical innovation) and another 55 % realized innovations which are at least new to the firm.

As shown in Table 10, for the surveyed Vienna ICT companies the local level is highly relevant for knowledge sharing activities with multiple partners during the innovation process. For knowledge linkages to clients, service firms, technology centers and particularly universities the Vienna region is even the most important interaction space. The empirical findings, thus, suggest that in the Vienna ICT industry localized knowledge circulation is pivotal. Consequently, there are hardly any reasons for assuming that fragmentation is a dominating feature in this knowledge based sector. To be sure, there is also evidence of innovation networking with national and international partners such as clients, suppliers and other knowledge sources, pointing to a rather high degree of embeddedness of Viennese ICT firms into the national innovation system and European knowledge networks. The firms in this sector, thus, demonstrate both local and international knowledge links.

Concerning the modes of knowledge exchange we found a clear dominance of informal networks and spillovers (Table 11). Informal contacts, reading scientific publications, monitoring competitors, participating in conferences and fairs, as well as recruiting highly qualified people turned out to be the favorite knowledge sourcing activities performed the surveyed companies. Except from R&D collaborations formal networks play a negligible role. The same holds true for market links. This is a clear difference to the biotechnology sector where knowledge flows show a more formalized nature.

Table 11: Mechanisms of knowledge transfer (% of all responding ICT firms)

	% of firms
Market linkages	
Contract research	22
Consulting	20
Buying licenses	9
Buying machinery, software	20
Formal co-operations	
R&D collaborations	32
Joint use of R&D facilities	9
Spillovers and informal networks	
Recruiting specialists	41
Monitoring competitors	52
Reading scientific publications	55
Informal contacts	61
Participating in conferences/fairs	42

In the following we have a closer look on two key channels of knowledge transmission, namely labor market recruitment and R&D collaborations, focusing particularly on the geography of these modes of knowledge exchange.

As it is shown in Table 12, the local labor market plays a crucial role for innovating Viennese ICT firms. Indeed, there is evidence of strong knowledge flows from universities, technical colleges and ICT companies to the surveyed firms via mobility of highly skilled labor. At the same time we could observe that also the national labor market and universities located in other countries are relevant when it comes to recruit specialists. In comparison, labor mobility among companies is a less important mechanism for knowledge transfer.

Table 12: Recruiting highly qualified workers – sources and geography (% of all responding ICT firms)

	Vienna	Austria	International
Universities	49	23	19
Technical colleges	38	29	7
Companies	33	25	9

As noted above, about 40% of the ICT firms included in the sample are involved in R&D co-operations. The analysis of the spatial dimension of these formal linkages reveals that R&D collaborations are highly localized in nature (Table 13). These findings differ from some other studies which have pointed to a highly international character of such formal R&D collaborations and knowledge “pipelines” (Hagedoorn 2002, Bathelt et al. 2004). The surveyed ICT companies maintain such links with a variety of local partners. We could observe a particular strong role of local universities, local customers and local competitors. To a lesser extent, R&D co-operations are also found with partners at the national and European levels, whereas other parts of the world (USA and Canada, Asia, other countries) are negligible.

Table 13: Spatial pattern of R&D co-operations (% of all responding ICT firms)

	Vienna	Rest Austria	EU-EFTA	USA & Canada	Asia	Rest of the World
Customers	15	12	9	1	1	0
Suppliers	9	7	7	0	0	0
Competitors	15	6	6	0	0	0
Service firms.	10	4	4	0	0	0
Commercial R&D	13	9	3	0	0	0
Universities	19	6	4	3	1	0
Technical Colleges	10	10	0	0	0	0
Non-profit R&D	6	6	4	0	0	0
Technology centers	9	4	0	0	0	0

The role of policy in promoting the local embeddedness of Vienna’s biotechnology and ICT sectors

The empirical findings reported above provide evidence for a high degree of embeddedness of Viennese biotech and ICT firms, brought about by rather vivid knowledge sharing activities and innovation partnering at the local level. Arguably, the intensity of local knowledge circulation found in the biotech and ICT sectors has – to some extent – been positively influenced by conscious policy efforts. In the past 10 years, stimulation of knowledge links has become a core strategy of innovation and technology policies, both at the national and the local levels. We find various national initiatives which explicitly aim at fostering knowledge interactions in biotechnology (such as the Genome Research Program and the initiative LISA-

Life Science Austria) and in ICT (for example the FIT-IT program). Furthermore, the local biotech and ICT sector benefit from the so called “Competence Centre program” which promotes the establishment of new research centers, which are jointly run by universities and companies. In sharp contrast to the past, fostering knowledge linkages is also at the top of the local policy agenda today. For a long time, Vienna’s economic policy was about providing subsidies to individual companies and attracting multinational companies. It was only by the end of the 1990s that issues of innovation and technology gained importance. Today, Vienna’s strategic policy priorities are on life sciences, ICT, creative industries and the automotive sector. This reorientation has been accompanied by a process of institution building. At the beginning of the new millennium new funding organizations have been created. They have special programs for biotechnology and ICT, organized as contests of proposals. Another new centre is “Inits”, which has been founded in 2003. Its aim is to support technology-oriented spin-offs from the academic sector by offering counseling and assistance to scientists in the process of turning a good idea into a viable business. Overall, the local policy system has undergone a far reaching transformation. The new policy routines are strongly about promoting high tech industries and fostering local knowledge connections.

4 Summary and conclusions

Metropolitan regions are often considered as centers of innovation and knowledge intensive activities, and they are regarded as key nodes of knowledge networks. They are usually well equipped with public and private research organizations, universities and higher educational institutions as well as with high ranking business services (Brower et al. 1999, Simmie 2003). However, not all metropolitan regions are vibrant innovation systems. Some of these regions suffer from a problem of fragmentation in their respective RIS (Tödtling and Trippl 2005). They may lack sufficient interaction between the RIS subsystems of knowledge generation and knowledge exploitation. Also a certain level of knowledge exchange among firms might be missing.

Vienna seems to be a case in point for this phenomenon. On the one hand it is clearly the key centre of research and higher education as well as of knowledge intensive sectors and business services within Austria. On the other hand its RIS has shown characteristics of fragmentation in some previous studies. In particular there was little interaction between the research sector (mainly made up by public universities) and the business sector.

Our recent investigations of two growing knowledge intensive sectors in the region, the biotech industry and the ICT sector, have demonstrated that fragmentation within the Vienna RIS may not be the prime innovation barrier any longer. Both for the biotech sector and for the ICT sector we found quite intensive knowledge interactions at the regional level. Firms in both sectors were also linked to international partners in their innovation process. In addition we found a variety of knowledge interactions, both formal (market links and formal co-operations) and informal (knowledge spillovers and informal contacts) ones. Policies at the regional and national levels in the past decade might also have contributed to a higher level of innovation networking.

Barriers for the development of these sectors, however, still exist. First, as other investigations have shown (Trippel et al. 2007) there are quite strong differences among companies in their level of innovation and innovation interaction. Such a segmented nature is clearly visible in the ICT sector where some large, partly international firms with a high level of R&D activities and some dynamic SMEs exist next to a large segment of very small firms which are not able to perform any R&D or to maintain relationships to research organizations. Then, in the biotech sector there seems to be a lack of critical mass. So far there are rather few dedicated biotech companies and spinoffs, partly due to missing entrepreneurial spirit among researchers and a lack of venture capital. Furthermore, Austria and Vienna do not have any home grown large pharmaceutical companies to act as leading firms in a local cluster. Consequently, the Vienna biotech sector, despite its recent growth, seems to be still in a rather vulnerable state.

Overall, we find that in some respects the metropolitan region of Vienna performs its function as a centre in the knowledge economy. At least for the two knowledge based sectors included in our studies, we could observe that Vienna's RIS has overcome its state of fragmentation found in earlier studies. For a dynamic and enduring development of knowledge intensive sectors, however, there are still barriers indicated above which should be targeted by respective policies. What remains obscure, so far, is whether local knowledge sharing activities have also grown in other sectors than those investigated here, reflecting a transformation of the whole RIS from a fragmented towards a more integrated one. More research considering a broader set of industries, thus, seems to be necessary to explore whether or not ICT and biotech constitute integrated islands in a fragmented RIS.

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